Institute of Space and Aeronautical Science, University of Tokyo
Report No. 576, January 1980

Maneuver of Spinning Rocket in Flight

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Abstract: A Yo-despin device successfully functioned to change in flight the precession axis of a sounding rocket for astronomical observation. The rocket attitudes before and after yo-despin were measured with a UV star sensor, an infrared horizon sensor and an infrared telescope. Instrumentation and performance of these devices as well as the attitude data during flight are described.

1. INTRODUCTION

Astronomical observation over a wide sky region can be hardly achieved by use of a telescope with a limited field of view on board a spinning rocket. If the rocket is spin stabilized, the field of view scans a circular belt according to spin and precession. If the coning angle of precession is large, the field of view can cover a rather wide sky region, as in our past X-ray observations (Hayakawa *et al.* (1975), Iwanami *et al.* (1979)), but with the sacrifice of statistical accuracy.

A compromise between the wide sky coverage and statistical accuracy can be achieved if the precession axis is changed during flight by despin. This has been motivated by a near-infrared observation of the galactic plane, so as to cover as wide as a possible range of the galactic longitude along the plane, aiming at an observation of the galactic longitude dependence of near-infrared radiation (Hayakawa *et al.* (1979)). An infrared telescope with its axis parallel to the rocket axis scans a circular belt by precession. A change of the precession axis in the midway of flight makes it possible to scan two circular belts which intersect the galactic plane at four different longitudes.

The present paper describes the instrumentation and the performance of the rocket maneuver and associated attitude sensors with use of a sounding rocket K-9M-64. Particular emphasis is put on a yo despinner and an ultraviolet (UV) attitude sensor, since their combination has been found useful.

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2. Yo Despinner

The yo despinner consists of a wire, a weight, and their release mechanism. The wire has one end fastened to the circumference of the rocket and is then wrapped around in a direction opposite to the direction of rotation. The weight is attached to the outer end of the wire and held against the circumference. At a given instance the weight is released by a pyrotechnic release mechanism. It swings out under the centrifugal force and, through the wire, exerts a retarding moment on the rocket. In addition to despinning of the rocket, this moment can also cause a precession torque when the line of reaction of wire release is displaced from the center of gravity of the rocket. The precession angle after wire release (Γ_f) is a function not only of performance of the yo despinner and the precession angle before weight release (Γ_0) but also of the phase of wire release. Since this phase is arbitrary, it is difficult to expect a precise value of Γ_f in advance of the flight.

The expected maximum and minimum values of Γ_f are shown in Fig. 1 for the configuration and the performance of the yo despinner listed in Table 1.

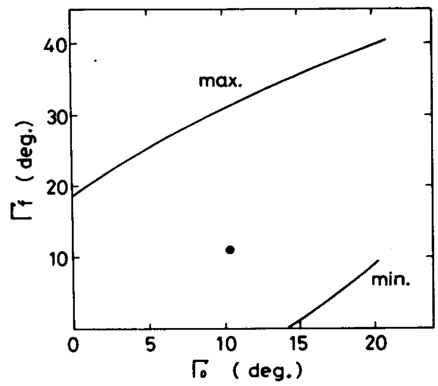

Fig. 1. The precession angle after wire release (Γ_f) versus that before weight release (Γ_0) calculated for the spin reduction ratio 0.737. The value of Γ_f lies between its maximum and minimum values indicated, depending on the phase of wire release. The values of Γ_0 and Γ_f achieved in the experiment are indicated by a solid circle.

Table 1. Yo Despinner Configuration and Performance (designed values)

Moment of inertia (roll)	0.356 kg·m·s^2
Moment of inertia (pitch)	61.85 kg·m·s^2
Yo weight	182 gr
Yo wire length	1556 mm
Yo wire weight	17.5 gr
Axial distance between CG and plane of wire wrapped	1611 mm
Spin reduction ratio	0.737

The experiment was successfully performed by a yo despin device incorporated with a sounding rocket K–9M–64. As shown by flight data (Table 2), the spin of K–9M–64 was reduced from 2.82 rps to 2.14 rps; hence the spin reduction ratio χ was 0.761. This

TABLE 2.

Flight Data

Rocket	K-9M-64	
Launch Time	August 20 1978 20:30 JST	
Apogee	319.5 km	
Despin	at 350 sec after launch	
	Before despin	After despin
Spin Period	354–356 m sec	466–467 m sec
Precession Period	57.5 sec	75.6 sec
Precession cone radius	10.5	10.9
Precession axis		
α (1950)	$18^h\ 55^m$	$19^h\ 23^m$
δ (1950)	21°.1	8°.1

value was only 3% greater than the designed value (0.737). The precession angle changed from 10.5 deg to 10.9 deg. This was also within the limits expected, as shown in Fig. 1.

The attitudes of the rocket before and after despin were measured with three attitude sensors, the infrared telescope itself, a horizon sensor for 15 μm radiation of CO_2, and an ultraviolet (UV) sensor sensitive to blue stars. Among them the UV sensor gave a quantitative result of the rocket attitude. This has provided the experimental verification of usefulness of the UV attitude sensor.

3. UV SENSOR

The UV sensor consists of a pair of UV counters with intersecting fields of view, so that the azimuth and elevation angles of a star with respect to the rocket axis can be obtained from the mean value and the difference of glancing times of these counters, respectively. The UV counter is a photomultiplier tube with a fused quartz side window and a Cs–Te opaque photocathode, HTV R427. Its effective sensitive band is 170–250 nm with the peak quantum efficiency of 0.2 at 230 nm, so that the Herzberg band ($\lambda > 260$ nm) of airglow is avoided, and the level of diffuse galactic UV light is relatively low compared with that of starlight. The effective area of 0.5 cm^2 is large enough to resolve several B-type stars with $m_v \lesssim 3$ by a single scan due to the rocket spin of about 3 rps.

The photomultiplier tubes and preamplifiers were contained in a box ($50 \times 103 \times 25$ mm^3) sealed with silicon rubber to protect them from vibration damage and high voltage break down, as shown in Fig. 2. These counters were incorporated with two carbon coated slat collimators whose fields of view were inclined by 45° with respect to the rocket axis. The full widths at half maximum were 2°.8 and 5°.8 in the directions of spin and rocket axes, respectively, as shown in Fig. 3. The elevation angle of the intersecting point was approximately fixed to be about 30°. The exact geometry after integration was measured in flight by observing stars.

The pulse signals of individual photons were selected by discriminators and counted

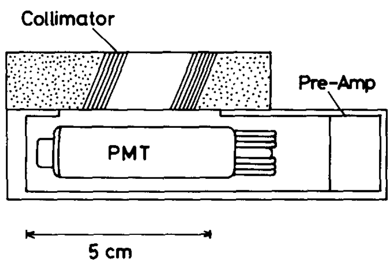

FIG. 2. The side view of the UV sensor.

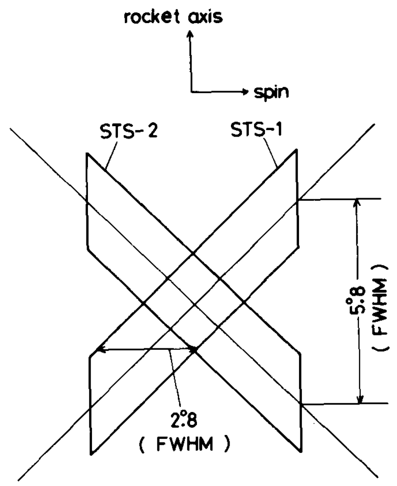

FIG. 3. The fields of view of two UV counters.

by up-down scalers. Digital counts were converted to DC voltage signals which were transmitted through IRIG channels Nos. 14 and 15 of an FM–PM telemeter.

4. HORIZON SENSOR

The horizon sensor consists of a germanium lens of 40 mmϕ and $F=1.5$ with a field of view of $1° \times 1°$. CO_2 emission at 15 μm is detected by a thermister with a filter of the effective band width of 1.8 μm.

The optical axis was perpendicular to the rocket axis. The optical system together with a signal processor was contained in a box ($67 \times 90 \times 85\,\mathrm{mm}^3$) underneath the infrared telescope.

The output signals due to CO_2 emission at a level of about 40 km from the ground were differentiated and amplified. The analog signals were transmitted through IRIG channel No. 13.

5. INFRARED TELESCOPE

Since details of the infrared telescope will be described elsewhere, we here only give a brief account necessary for attitude measurements. The optical axis was parallel to the rocket axis. Three detectors which properly functioned were located off the axis so as to scan a circle of radius 5° with the field of view 1°.4ϕ.

Bright infrared stars were detectable with the telescope so as to obtain the rocket attitude and to perform the calibration of the optical system.

6. PERFORMANCE

These instruments together with UV photometers and hard X-ray counters were on board a sounding rocket K–9M–64. The rocket was launched at 20:30 JST on 20 August 1978 from Kagoshima Space Center. The high voltage (900 V) of the UV counters was switched on at 40 seconds, and the nose cone was ejected at 60 seconds after launch. At 65 seconds after launch the rocket motion became stable. The spin period changed gradually from 354 ms to 356 ms, while the precession period was 57.5 s and the cone half angle of precession was 10°.5. The rocket reached the apogee at an altitude of 319.5 km at 283 seconds after launch. The despin was performed at 350 seconds after launch. Thereafter the spin period increased to 466–467 ms, while the precession slowed down to the period of 75.6 s with a cone half angle of 10°.9.

The flight curve is shown in Fig. 4, and the flight data are summarized in Table 2.

Since the solar zenith angle was 110°, the region below an altitude 430 km lied in the earth shadow. Effects of solar radiation on these attitude sensors were unappreciable. Strong airglow emission was detected right after the nose cone ejection both with the UV sensor and the infrared telescope, while a spin modulated signal of CO_2 emission was observed in most of the precession phase; in a part of the precession phase the field of view did not cross the horizon.

Above the airglow level, signals of the UV sensor and the infrared telescope were modulated by the galactic plane. The moon gave saturated signals of the UV sensor, which resulted in the loss of useful data over the angular range of about 60°. No appreciable contribution of the moon was detected by the infrared telescope.

Several bright stars were visible without superposition over spins. We used α And, γ Cas, η UMa, λ Sco, α Pav, α Gru, and β Cep detected with the UV sensor as well as δ Lyr and χ Cyg with the infrared telescope for the attitude determination. Necessary data of these stars are given in Table 3.

A change of attitude by despin was readily observed from signal patterns of three

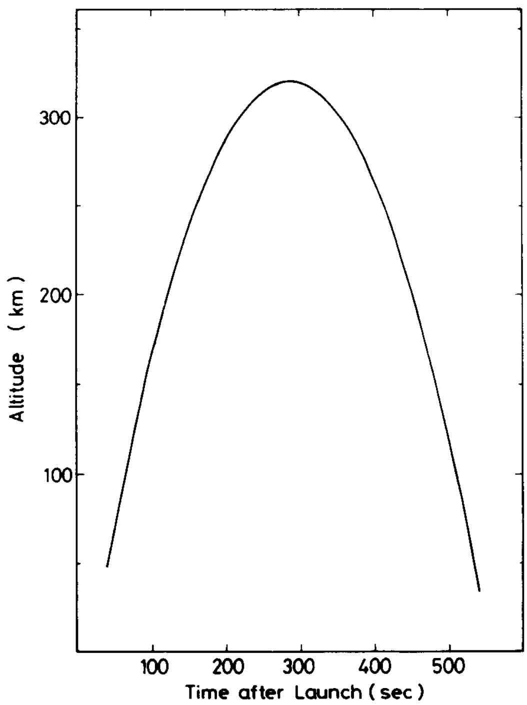

FIG. 4. Flight curve of K-9M-64.

TABLE 3.

Stars	m_v	Sp	α (1950)			δ (1950)		
α And	2.0	B9	0^h	05^m	47.8^s	$+28^\circ$	$48'$	$52''$
γ Cas	1.6–3.0	B0	0	53	40.3	+60	26	47
η UMa	1.9	B3	13	45	34.3	+49	33	44
λ Sco	1.6	B1	17	30	12.6	−37	04	10
α Cep	1.7	B5	21	17	23.2	+62	22	24
β Cep	3.3	B2	21	28	01.4	+70	20	28
α Gru	1.9	B3	22	05	05.4	−47	12	15
δ Lyr	6.3	M4	18	52	45.2	+36	50	03
χ Cyg	3.3–14.2	S7	19	48	38.5	+32	47	12

sensors. A decrease of the elevation angle of the rocket axis by about 10° was obtained from the horizon sensor. The field of view of the infrared telescope crossed the galactic plane at smaller longitudes, so that a wide longitude range was covered. No infrared star was detected after despin. The UV sensor provided the trajectory of the rocket axis. The maneuver turned out to be ideal for the infrared observation.

Near the end of the flight both the infrared telescope and the UV sensor detected airglow. Instruments functioned properly during the flight, except for a drift of signal levels of the infrared detectors.

7. DATA REDUCTION

Since quantitative results were obtained with the UV sensor, we describe the method of data reduction applied to the UV sensor data. A part of read-out data for the integrated counts of two UV counters and time marks are shown in Fig. 5. From them we obtained the counting rates versus time as shown in the bottom figures. Several bright stars are clearly distinguishable.

Let the zenith and azimuth angles of a star in the rocket frame of reference be θ and φ, respectively. They are related to the zenith angle ρ of the common axis of the counters in the same reference system and to the inclination angles of respective counters $\pm\delta$. From the geometrical relation shown in Fig. 6, we obtain

$$\tan\theta\left(\frac{\cos\varphi}{\tan\rho}+\frac{\sin\varphi}{\tan\delta}\right)=1\,.$$

The value of 2φ is derived from the time difference between two peaks attributed to the one and same star and the roll angular velocity. If ρ and δ are known, the value of θ is obtained. This gives a small circle on which the rocket axis is located on the sky. A crossing points of these circles gives the position of the rocket axis on the sky. This method would be exact if there were no precession. Since the precession period was 160 times the spin period in the present experiment, the above method is practically applicable without serious error.

Considering that the values of ρ and δ may be different from their preset values because of misalignment taking place in the course of integration, we measured their values during flight. A wrong choice of ρ and δ would result in a poor conversion of the

FIG. 5. An example of UV sensor data. The two top figures (a, b) represent the read-out data of the up-down scalers of two UV counters. The two bottom figures represent the counting rates versus the azimuthal angle for two counters.

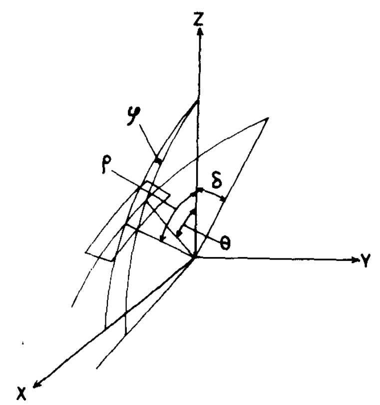

FIG. 6. The geometrical relation of angular variables. The z axis is parallel to the rocket axis. The field of view of the counter is shown by a parallelloid. The counter axis: ρ, δ; the star: θ, φ.

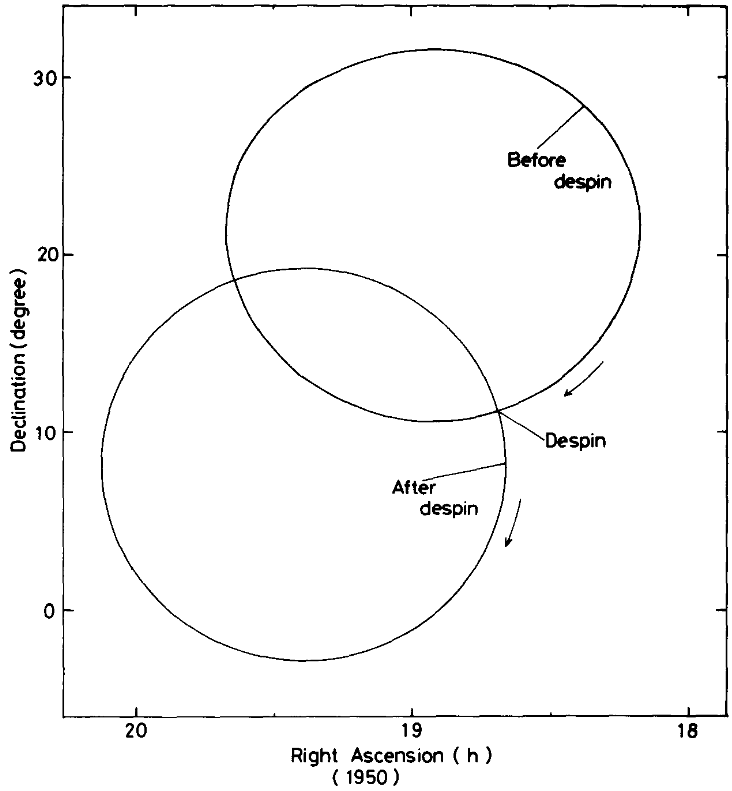

FIG. 7. The precession circles before and after despin.

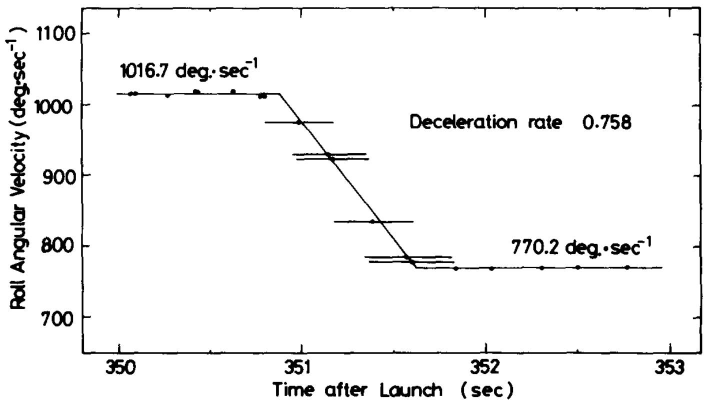

FIG. 8. The roll angular velocity versus time around the time of despin.

crossing points of the rocket axis circles. A trial and error method of finding the best conversion was applied by reference to the fact that two stars were found in the field of view of the infrared telescope before despin. Thus we obtain $\rho=71.5°$ and $\delta=39°$.

The trajectories of the rocket axis thus obtained before and after despin are shown in Fig. 7. An error associated with this procedure was found to be $\pm 0.3°$ in the celestial coordinate system.

The present method enables us to derive the rocket motion in the course of despin. The roll angular velocity changed as shown in Fig. 8. From this we estimate that the

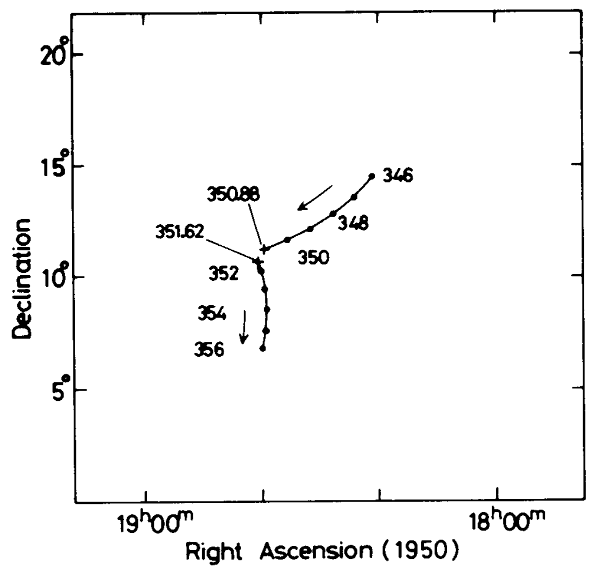

FIG. 9. The trajectory of the rocket axis around the time of despin.

despin process began at 350.88 ± 0.08 sec and finished by $351.62 \pm ^{0.23}_{0.03}$ sec after launch. The angular velocity decreased from 1016.7 deg s^{-1} to 770.2 deg s^{-1}, the reduction by a factor of 0.758. The trajectory of the rocket axis just before and after despin is derived in Fig. 9. During the despin process, the rocket axis moved 0.65°, and the full coning angle changed from 21.0° to 21.8°.

ACKNOWLEDGEMENT

It is our pleasure to express our thanks to the K-9M-64 staff for their cooperation in integration and launch. We also thank T. Matsumoto, H. Murakami and K. Uyama for their contributions to the horizon sensor and the infrared telescope. Thanks are also due to F. Nagase and H. Kunieda for the development of UV detectors.

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December 4, 1979

REFERENCES

Hayakawa, S., Kato, T., Tanaka, Y. Yamashita, K., Bleeker, J. A. M., and Deerenberg, A. J. M. (1975): Astrophys. J., **195**, 535.
Hayakawa, S., Matsumoto, T., Murakami, H., Noguchi, K., and Uyama, K. (1979): to be published.
Iwanami, H., Kunieda, H., Nagase, F., and Yamashita, K. (1979): Astrophys. Space Sci., **61**, 217.